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Original Article

Dependencies between indicators of the speed-power and balance stability of figure skaters

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Abstract
Figure skating is a sport that combines endurance, strength, flexibility and grace with a touch of artistry. Since it is one of the early specialized sports monitoring training results and physical development, regularly performing and evaluating anthropometric measurements and fitness tests in and out of group comparisons can be useful for monitoring performance. One of the characteristics of modern figure skating is the progressive complexity of competitive programs. This process develops, in particular, in terms of the way athletes master elements and compounds of a rotational nature that are complex in terms of coordination, which is a strong irritant for the vestibular analyzer. The *goal* of this study is to determine the dependence between the speed-power capabilities and the indicators of equilibrium stability of figure skaters. The following *tasks* were set: measuring speed-force indicators with the "BTS G-sensor" equipment, measuring biomechanical dynamometric characteristics, and deriving correlation dependencies between speed-force indicators and balance stability. The correlation analysis of the sample test indicators involves analysis using multiple Pearson's correlations. The indicators are biomechanical indicators, comprising kinematic, dynamic and equilibrium indicators. Intragroup correlation coefficients were present for the biomechanical characteristics of the kinematic and dynamic type, particularly for the squat jump type. A significant coefficient of correlation was found between speed-power qualities and indicators of vestibular stability in the type of bounce with the help of the arms (CMJA), which is an indicator of the coordination of movements. The results of the conducted studies allow us to consider that a decrease in the stability of the vestibular system of figure skaters occurs due to fatigue, as well as a decrease in the level of their special endurance. These data are to some extent explained by changes in the vestibular sensory system, which leads to the occurrence of technical errors when figure skaters participate in competitive programs.
Keywords: Figure skating, speed-strength qualities, indicators of equilibrium stability, correlations.

Introduction

Figure skating is a sport that combines endurance, strength, flexibility and grace with a touch of artistry. A high level of discipline forces increasing numbers of young athletes to train in excess of the norms that are considered safe for a young, growing body (Porter, Young et al., 2007). Since it is one of the early specialized sports (American Academy of Pediatricians (AAP), 2000) monitoring training results and physical development, regularly performing and evaluating anthropometric measurements and fitness tests both in and out of group comparisons can be useful for monitoring performance.

Figure skating is a sport with a complex coordination structure, in which movements on the ice are performed through turns, changes of direction and speed, combined with additional elements, such as jumps, jump combinations and jump sequences, step sequences, lifts, twist lifts, throw jumps, death spirals, spins and entering into them. The highly developed coordination abilities of the figure skater accelerate the learning of various technical elements of figure skating and the ability to quickly change the characteristics of movements, when it is necessary to perform specific movements or in case of errors that occur during the gliding process (Groshev, 2018). The new requirements for the skills of figure skaters determine the appropriate organization, content and conduct for the educational and training process. One of the characteristics of modern figure skating is the progressive complexity of competitive programs. This process develops, in particular, in terms of athletes mastering elements and movements of a rotational nature which are complex in terms of coordination, and also a strong irritant for the vestibular analyzer. Therefore, one of the specific features of figure skating is the dependence of sports results in this sport on coordination capabilities and vestibular stability (Osadchenko, 2017).

Figure skating refers to stereotypical acyclic movements evaluated by the quality of performance (Kuznetsov & Novikov, 1977; Medvedeva, 2002). First of all, there is the management of complex coordinated motions in space and time, extreme flexibility in joints, the maintenance of balance, and special requirements for motion control under conditions of limited support and without support. In many movements there are special

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features of control: the expressiveness of movements, their aesthetic side, emotional coloring, and artistry. The level of performance in figure skating is assessed by a number of controllable parameters: orientation in space and time, complex coordination, strength and speed of movement, balance, flexibility, impeccability, and expressiveness (Farfel, 1975; Medvedeva, 2002).

Modern figure skating is characterized by the complexification of the programs and filling them with complex jumps. This requires strong reliance on and stability of technical skills, which can be achieved only with a high level of development of the speed-and-force qualities of young figure skaters (Bukhartseva, 1973; Tikhomirov, 1974; Medvedeva, 2002). Among the many forms of manifestation of speed-force qualities, the most important for the figure skater is the manifestation of "jumpiness" (Landl, 1982). Most experts agree that in adult athletes, muscle strength is the main component of jumping ability (Dyachkov, 1967; Zatsiorsky, 2019; and others).

Mishin (2021) has argued that jumping is necessary and has suggested that the child's predisposition to jumping in figure skating should be analyzed from two points of view: from the point of view of the height and the length of the jump, and from the point of view of the ability to use the obtained speed in terms of acceleration time, the tendency to use free swing movements during repulsion, and the ability to rotate in the air. It should be borne in mind that the ability to rotate around the longitudinal axis of the body during flight is extremely important (Mishin, 1973). The ability to sharply group and to achieve high rotation speed is the basis for multi-rotational jumps. More promising (in the absence of both qualities at the same time) should be considered a skater with a pronounced ability to rotate during the flight (it is easier to increase the height of the jump than to develop the ability to rotate during the flight). In addition, athletes with a pronounced talent for rotational movements are more stable when performing multi-rotational jumps. This quality is especially evident during competitions. The ability to bounce, especially pushing off with the left and right foot separately, is a very important quality for the figure skater (Bukhartseva, 1973; Gandelsman & Reisner, 1975; Landl, 1982).

The figure skater's ability to orient him- or herself in space and time, to perform the most complex movements quickly and accurately under conditions of little and unstable support is achieved by perfecting the analyzers involved in equilibrium reactions. Apart from the vestibular, they include the visual and motor analyzers. Balance is the ability of a person to hold the body or individual parts of the body in a certain position as a result of complex joint activity of a number of organs and systems, aimed at combating the forces of gravity. A sufficient level of balance ability allows a figure skater to master the complex techniques of various physical exercises more quickly, at a higher technical level (Bondarevsky, 1976).

Studies (Yalkos, 1962) have demonstrated that figure skaters are able to withstand rotational loads of exceptional mahasgnitude and at the same time maintain accuracy of movement.

King (2018) has estimated that professional female skaters often leap about 0,40 m off the ice. But the ability to jump high comes at a cost. In order to increase jump height, a skater must increase their strength. However, an increase in strength often means an increase in muscle weight – which could mean a slower rotational speed.

Very few studies have been devoted to the problem of balance and vestibular stability in sports. Modern research is primarily focused on methods for improving static and dynamic balance in rhythmic gymnasts (Agostini, 2019) and evaluating correlations between dynamic stabilometric testing of young soccer players (Sikora, 2020). In figure skating, research studies are mainly aimed at subjects such as developing coordination abilities (Gubaeva, 2015), studying the biomechanical characteristics of the jumps (Knoll, 2019), and methods for improving the technique of the spins (Ivanova, 2018).

In our previous research, we found that the final result in figure skating depends most on the quality performance of the jumping elements, and the tendency for this dependence is increasing (Yordanova, 2017). For a high-quality performance of the jumps, certain specific characteristics are indicated, as reflected in the ISU Communication (2022). The most important of these characteristics is a good height and a very good length. This contributes to a higher mark in the Grade of Execution (GOE) by the judges, but also in the easier execution of the jumps with more revolutions in the air (Mishin, 2021).

The goal of this study is to determine the dependence between the speed-power capabilities and the indicators of the equilibrium stability of figure skaters.

Material and methods

The subject of the study is the dialectical connection between the indicators of speed-power readiness and balance stability, with special reference to the jumping elements of young figure skaters.

The object of the study is the structure of speed-power readiness and balance stability in adolescent figure skaters.

Participants. The study included a total of 15 competitive female figure skaters aged 11 to 13 (prepuberty) in the category of single skating from skating sports clubs in the Republic of Bulgaria. The skaters' competition levels ranged from Basic Novice to Juniors (as determined by their participation in Bulgarian National Championships and ISU competitions), with all skaters able to perform at least double revolution jumps on the ice. The typical sensitive period for developing motor skills such as speed-strength and balance are between 10 and 14 years of age.

For the purpose of the study, the following *tasks* were set: measuring speed-force indicators with the "BTS G-sensor" equipment, measuring biomechanical dynamometric characteristics, and deriving correlation dependencies between speed-force indicators and balance stability.

The following methods were used in the study: systematization and analysis of data from scientific methodical literature, pedagogical observation, sports pedagogical testing, and methods of mathematical statistics.

To obtain current and aggregate information about the latent state and dynamics of development of individual features and components of the motor abilities of the subjects, a battery of tests was used (Table 1).

Table 1. Measured parameters.

№	Measured parameters	Measure units	Measurement accuracy
	Biomechanics indicators		
1	Squat jump (SJ)	[cm, kN, m/s]	0,01
2	Counter movement jump (CMJ)	[cm, kN, m/s]	0,01
3	Counter movement jump with arms rush (CMJA)	[cm, kN, m/s]	0,01
4	Drop jump (DJ)	[cm, kN, m/s]	0,01
5	Repeated counter movement jumps (RCMJ)	[cm, kN, m/s]	0,01
	Biomechanical dynamic indicators		
6	Average (Romberg and landing test)	[cm]	0,01
7	Frequency (Romberg and landing test)	[Hz]	0,01

With the help of instrumental methods, the explosive strength of the lower limbs and the effectiveness of jumping ability were studied (tests 1–5) using the "BTS G-sensor" accelerometer. The device is a technique for studying various parameters that can be implemented and observed with a certain type of jump. Five types of jumps were performed in laboratory conditions, in which the following parameters were measured: jump height [m]; rebound force (repulsion) [kN]; impact force with support (depreciation) [kN]; maximum concentric force [kN]; average speed in the repulsion phase [m/s]; peak speed [m/s]; bouncing speed [m/s]. All data were recorded in separate protocols for each participant.

Biomechanical dynamometric parameters were measured by stabilometry when performing two exercises for a fixed time. The two exercises were the balance in the "Romberg" position, in which the upper limbs are laid aside in a horizontal plane, the gaze is directed forward, and the sole of the free leg rests on the knee of the supporting leg; and the landing position after the jump, which is typical for figure skating.

Data analysis

The results of the study were processed with mathematical-statistical methods, namely correlation analysis with the statistical program package IBM SPSS Statistics Version 26 and MS Office 2018. Correlation analysis was used for processing statistical data used to study coefficients (correlations) between variables. The analysis compares the correlation coefficients between one or more pairs of variables to establish statistical relationships between them.

Results and discussion

Figure skating jumps are an integral part of motor activity. One of the conditions for their good performance is great height and length. The criteria for this are the indicators of speed-power qualities, as well as the coordination capabilities and stability of the vestibular apparatus. In a study of differential development of the speed-power capabilities in terms of bounce, it was found that in girls and junior women the highest percentage of development was observed between the ages of 10 and 14 (Volkov, 1981; Grodzicka, 1983; and others).

A number of studies have shown that, despite the bounce to some extent, by applying effective exercises, the level of the speed-power preparation of athletes can be significantly increased (Verhoshansky, 2020). The figure skater's ability to navigate in space and time, quickly and accurately performing the most complex movements under conditions of little and unstable support, is achieved by improving the analyzers involved in equilibrium reactions. A good level of balance development allows for faster mastering of the complex technique of various physical exercises at a higher technical level. The organ for balance, as is known, is the vestibular apparatus that ensures the position of the body and its orientation in space. It is a peripheral receptor that is part of the vestibular analyzer. The vestibular apparatus "controls" the position and movement of the body in space and the muscle tone. In all cases of the normal functioning of the vestibular apparatus, an important role is played by acceleration – for example, rectilinear (when the body moves in a straight line) and angular acceleration (during rotations).

This study of the balance stability of female figure skaters was realized by testing in the Romberg position and testing in the landing position after a height bounce. During the Romberg test, the athlete raises the foot to the knee, without touching it, and executes the balance on one foot for the specified test time, but not shorter than 30 seconds in a static position. When landing after the jump, the athlete seeks to achieve the minimum equilibrium oscillations as quickly as possible, which is an active process for the muscles to master balance during the test, as well as to establish the presence of a downward trend in the amplitude of the equilibrium oscillations. This ability of the balance apparatus is valuable for improving the sports and the technical skills of figure skaters.

The basic movement of figure skating is sliding, mainly in a single support position. The art of sliding is achieved as a result of mastering a number of components, such as the correct posture, a sense of balance, etc. (Mishin, 1981). G. Lussy and M. Richards (1959) stated that “the first condition for learning figure skating, without which progress is absolutely impossible, is to find the correct and natural balance. Only with a sense of balance can one successfully master the movements in figure skating.”

The correlation analysis of the sample test indicators involved analysis through the multiple Pearson correlations. The indicators form the biomechanical indicators, composed of kinematic, dynamic, and equilibrium indicators.

Table 2 presents the correlation analysis for the squat jump (SJ). Intragroup correlation coefficients were present for the biomechanical characteristics of the kinematic and dynamic types – jump height / maximum force hSJ / FSJmax (0.556), jump height / maximum speed hSJ / VSJmax (0.674), jump height / time hSJ / tSJ (0.500). The correlation coefficients cited so far are positive and, by their nature, express a proportional dependence between the indicators presented in the study. This fact means that as one of them increases, the other will increase too. Between the height and the acceleration hSJmax / aSJ is obtained (-0.602), a value that has a negative sign and certifies that an increase in one of them will lead to a decrease in the other. Significant positive coefficients were observed in the Romberg posture for amplitude and maximum force, Average / FSJmax (0.538), and for amplitude and repulsion time, Average / tSJ (0.661). These positive dependencies mean that with an increase in the maximum repulsive force, FSJmax, the amplitude of the equilibrium oscillations Average also increases. In the group including the equilibrium fluctuations, there are significant correlation coefficients: Factor Romberg / Average (0.705), Factor Romberg / Frequency (-0.526). These dependencies are determined by the formula for calculating the coefficient for the equilibrium, Factor = Average / Frequency, where Average is the average value of the maximum deviations in the equilibrium function, and Frequency is the frequency (the total number of these deviations as maximum and minimum values per second). Thus, these extremes determine how effectively the balance apparatus interacts with the support area. The nature of the jump being performed from the support should also be considered, with the preliminary setting of the kinematic chain in the semi-squat position.

Table 2. Correlations between biomechanics indicators for type SJ rebound and balance variables.

hSJ [m]	hSJ [m]										
FSJmax [kN]	**,556***	FSJmax [kN]									
VSJmax [m/s]	**,674****	**,745****	VSJmax [m/s]								
tSJtakeoff [s]	**,500***	**,967****	**,710****	tSJtakeoff [s]							
aSJ [m/s2]	**-,602***	**-,903****	**-,739****	**-,894****	aSJ [m/s2]						
Average [cm] Romberg	-,028	**,538***	,330	**,661****	-,360	Average [cm]					
Frequency [Hz] Romberg	,048	-,031	,109	,041	-,169	-,137	Frequency [Hz]				
Factor Romberg	-,117	,374	,217	,456	-,263	**,705****	**-,526***	Factor			
Average [cm] Landing	-,241	,192	-,042	,126	,045	,243	-,033	,128	Average [cm]		
Frequency [Hz] Landing	-,201	-,316	-,370	-,284	,292	-,089	-,001	-,010	-,309	Frequency [Hz]	
Factor Landing	-,302	,155	-,211	,124	,069	,237	,024	,138	**,860****	,084	Factor

** Correlation is significant at the 0,01 level (2tailed). * Correlation is significant at the 0,05 level (2tailed).
Note. Marked variables in bold and with * or ** indicate the presence of significant dependencies.

When considering the correlation model (Table 3), related to the vertical bounce of two legs without the help of hands, the significant between-group coefficients between amplitude and factor in the Romberg test and maximum force, Average / FCMJmax e (0.536), Factor / FCMJmax – 0.511, means its proportional increase in relation to the applied force. The negative correlation indicating an inverse relationship between maximum acceleration and take-off time, aCMJ / tCMJ (-0.562), is logically justified.

Table 3. Correlations between biomechanics indicators for type SMJ rebound and balance variables.

hCMJ [m]	hCMJ [m]										
FCMJmax [kN]	**,639****	FCMJmax [kN]									
VCMJmax [m/s]	**,776****	**,831****	VCMJmax [m/s]								
tCMJtakeoff [s]	**,712****	,162	,151	tCMJtakeoff [s]							
aSCMJ [m/s2]	,107	**,607****	**,706****	**-,562***	aCMJ [m/s2]						
Average [cm] Romberg	,117	**,536***	,344	-,174	,443	Average [cm]					
Frequency [Hz] Romberg	-,138	,140	,066	-,186	,229	-,137	Frequency [Hz]				
Factor Romberg	,174	**,511***	,323	-,078	,351	**,973****	-,341	Factor			
Average [cm] Landing	,272	,449	,366	,020	,320	,415	,144	,372	Average [cm]		
Frequency [Hz] Landing	-,174	-,234	-,252	,081	-,196	-,089	-,001	-,102	-,414	Frequency [Hz]	
Factor Landing	,147	,174	,241	-,138	,232	,142	-,024	,141	**,597***	**-,924****	Factor

In the jump with swing movement of the upper limbs, CMJA (Table 4), in addition to the expected intergroup relationships, there were relationships between the kinematic indicators' acceleration, aCMJA, in relation to Factor Romberg (0.576), Factor Romberg in relation to the speed VCMJA (0.557), and maximum force FCMJAmax (0.600). The correlation between the amplitude of the fluctuations for maximum force, maximum speed, and acceleration is significant. The Pearson coefficient is Avarege / FSMJAmax = 0.581, Average / VSMJAmax $r = 0.547$, and Average / aSMJA $r = 0.559$. In figure skating, the upper limbs are clearly used to change kinematic characteristics, such as angular speed of rotation, through the biomechanical principle – a law of conservation of angular momentum in rotational motion with great application in the rotational jump: $J \cdot \omega = const.$

Table 4. Correlations between biomechanics indicators for type SMJA rebound and balance variables.

hCMJA [m]	hSMJA [m]										
FCMJAmax [kN]	**,793****	FSMJAmax [kN]									
VCMJAmax [m/s]	**,832****	**,886****	VSMJAmax [m/s]								
tCMJAtakeoff [s]	,467	,085	-,086	tSMJAtakeoff [s]							
aSCMJA [m/s2]	**,506***	**,756****	**,898****	**-,504***	aSMJA [m/s2]						
Average [cm] Romberg	,348	**,581***	**,547***	-,123	**,559***	Average [cm]					
Frequency [Hz] Romberg	,020	-,132	-,180	,298	-,281	-,137	Frequency [Hz]				
Factor Romberg	,344	**,600***	**,557***	-,145	**,576***	**,973****	-,341	Factor			
Average [cm] Landing	,361	,314	,281	,161	,160	,415	,144	,372	Average [cm]		
Frequency [Hz] Landing	-,146	-,071	-,181	,077	-,158	-,089	-,001	-,102	-,414	Frequency [Hz]	
Factor Landing	,168	,023	,158	-,012	,110	,142	-,024	,141	**,597***	**-,924****	Factor

There is a very large intra-group relationship (Table 5) between maximum speed and acceleration; the Pearson coefficient is 0.964. There is a strong correlation between jump height and takeoff force, $r = 0.758$, between takeoff time and maximum speed, $r = 0.799$, and also between takeoff acceleration and takeoff time, $r = –0.851$. In this type of rebound, there is a significant action of the muscles of the lower limbs in depreciation mode. The coefficients of an intergroup nature are significant, between maximum force – amplitude in the Romberg pose FDJmax / Average $r = 0.594$, maximum force – factor FDJmax / Factor $r = 0.589$. A significant dependence is found between the frequency of fluctuations and the repulsion time, but with a negative sign, Frequency / tDJtakeoff $r = –0.512$.

Table 5. Correlations between biomechanics indicators for type DJ rebound and balance variables.

hDJ [m]	hDJ [m]										
FDJmax [kN]	**,758****	FDJmax [kN]									
VDJmax [m/s]	**,527***	,348	VDJmax [m/s]								
tDJtakeoff [s]	,092	,199	**-,779****	tDJtakeoff [s]							
aDJ [m/s2]	,324	,225	**,964****	**-,851****	aDJ [m/s2]						
Average [cm] Romberg	,285	**,594***	,223	-,022	,201	Average [cm]					
Frequency [Hz] Romberg	-,080	-,051	,424	**-,512***	**,490***	-,137	Frequency [Hz]				
Factor Romberg	,323	**,589***	,111	,116	,061	**,973****	-,341	Factor			
Average [cm] Landing	,193	,242	,336	-,275	,327	,415	,144	,372	Average [cm]		
Frequency [Hz] Landing	-,172	-,087	-,166	,072	-,147	-,089	-,001	-,102	-,414	Frequency [Hz]	
Factor Landing	,096	-,009	,206	-,166	,218	,142	-,024	,141	**,597***	**-,924****	Factor

When performing jumps of this motor structure – 20 vertical jumps performed consecutively (Table 6) – there are fewer significant correlation dependencies, primarily related to the maximum rebound speed, VRCMJ, compared to the repulsion models proposed in the study. Significant intergroup dependencies were observed only between the amplitude of fluctuations in the Romberg position and in the landing position with acceleration, respectively, $r = 0.547$ and $r = 0.539$.

Table 6. Correlations between biomechanics indicators for type RSMJ rebound and balance variables.

hRCMJ [m]	hRCMJ [m]										
FRCMJmax [kN]	**,556***	FRCMJmax [kN]									
VRCMJmax [m/s]	**,814****	**,662****	VRCMJmax [m/s]								
tRCMJtakeoff [s]	**,847****	,283	,393	tRCMJtakeoff [s]							
aRCMJ [m/s2]	,018	,366	**,587***	**-,500***	aRCMJ[m/s2]						
Average [cm] Romberg	,059	,417	,364	-,235	**,547***	Average [cm]					
Frequency [Hz] Romberg	,268	-,099	,361	,087	,262	-,137	Frequency [Hz]				
Factor Romberg	-,009	,439	,257	-,247	,453	**,973****	-,341	Factor			
Average [cm] Landing	-,017	,248	,339	-,293	**,539***	,415	,144	,372	Average [cm]		
Frequency [Hz] Landing	-,126	-,141	-,145	-,050	-,059	-,089	-,001	-,102	-,414	Frequency [Hz]	
Factor Landing	,028	,068	,149	-,099	,200	,142	-,024	,141	**,597***	**-,924****	Factor

Conclusion

Analysis of specialist literature shows that, among the most important specific motor capabilities of female figure skaters that determine sports achievement, we can refer to speed-power abilities, coordination of movements, and stability of the vestibular apparatus. Studies conducted previously have shown a certain dependence on the studied indicators described above.

The level of development of modern figure skating is characterized by extremely high sports achievements and sharply increased competition in the international sports arena, which necessitates the search for new ways to improve skaters' training.

Special training of athletes is developed considering not only the physical abilities of muscles to exhibit qualities, but also biomechanical conditions, and their implementation for specific elements of figure skating. The motor activity of figure skaters is influenced by specialized types of perceptions: a sense of ice, a sense of time and space, and a sense of partner. They are based on muscular, visual, auditory, and vestibular sensations that develop and improve in parallel with physical qualities and motor skills.

In figure skating, there is a direct relationship between the level of development of vestibular stability and the quality of performance of complex elements associated with body rotation, the accuracy of differentiation in the space, and the quality of the formation of motor skills.

The vestibular system, which perceives and processes the irritation of the receptors of the vestibular apparatus during rectilinear and angular accelerations experiences a high level of irritation. All movements of figure skaters consist of repeated accelerations during the execution of competitive programs and during training. Therefore, figure skaters need a high stability of the vestibular sensory system.

The results of the conducted studies allow us to consider that a decrease in the stability of the vestibular system of figure skaters occurs due to fatigue, as well as a decrease in the level of their special endurance. These data are to some extent explained by changes in the vestibular sensory system, which leads to the occurrence of technical errors by figure skaters when performing in competitive programs.

Conflicts of interest – The authors declare no conflict of interest.

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